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SITE
SUPERFUND INNOVATIVE
TECHNOLOGY EVALUATION

Technology Demonstration Summary

International Waste Technologies In Situ Stabilization/Solidification, Hialeah, Florida

A demonstration of the International Waste Technologies (IWT) process, utilizing the Geo-Con, Inc., deep-soil-mixing equipment has been performed under the Superfund Innovative Technology Evaluation (SITE) Program. This was the first field demonstration of an in situ stabilization/solidification process. The demonstration occurred in April 1988 at the site of a General Electric Company electric service shop in Hialeah, FL, where the soil contained polychlorinated biphenyls (PCBs) and localized concentrations of volatile organics and heavy metal contaminants. The demonstrated process mixed in situ the contaminated soil with a mixture of a proprietary additive, called HWT-20, and water.

The technical criteria used to evaluate the effectiveness of the IWT process were contaminant mobility, based on leaching and permeability tests; and the potential integrity of solidified soils, based on measurements of physical and microstructural properties. Performance of the Geo-Con deep-soil-mixing equipment was also evaluated.

The process did appear to immobilize PCBs. However, because of the very low PCB concentrations in the leachates, caused in part by the low concentrations of PCBs in the soils, absolute confirmation of PCB immobilization was not possible. Physical properties were satisfactory except for the freeze/thaw weathering tests, where considerable degradation of the test specimens occurred. The microstructural analyses showed that the process produced a dense, homogeneous mass with low porosity.

The Geo-Con deep-soil-mixing equipment performed well, with only minor difficulties encountered, which can be easily corrected. The HWT-20 additive was well dispersed into the soil, as evidenced by the relatively uniform change in chemical and physical characteristics of treated soil versus untreated soil.

The estimated remediation cost with operation of the 1-auger machine used for the demonstration is \$194/ton (\$150/yd^3). For larger applications, using Geo-Con's 4-auger machine, costs would be lower.

This Summary was developed by EPA's Risk Reduction Engineering Laboratory, Cincinnati, OH, to

announce key findings of the SITE program demonstration that is fully documented in two separate reports. (see ordering information at back).

Introduction

In response to the Superfund Amendments and Reauthorization Act of 1986 (SARA), the U.S. Environmental Protection Agency's Office of Research and Development (ORD) and Office of Solid Waste and Emergency Response (OSWER) have established a formal program to accelerate the development, demonstration, and use of new or innovative technologies as alternatives to current containment systems for hazardous wastes. This new program is called Superfund Innovative Technology Evaluation, or SITE.

The major objectives of the SITE Program are to develop reliable cost and performance information. One process, which was demonstrated in April 1988 at a General Electric (GE) electric service shop in Hialeah, FL, as part of the SITE Program, was the International Waste Technologies (IWT) in situ stabilization/solidification process, using the Geo-Con, Inc., deep-soil-mixing equipment. This was the first field demonstration of an in situ stabilization/solidification process. In this demonstration, both the IWT and Geo-Con technologies were evaluated. The test was performed to meet the goals of the SITE Program along with those of GE. GE's goals, which were developed independently of the SITE Program, were to fulfill the requirements of the Metropolitan Dade County Environmental Resources Management (MDCERM) to demonstrate, prior to the full site remediation, that this treatment method would immobilize PCBs. The SITE project, proposed to determine the technological and economic viability of the IWT process and the Geo-Con deep-soil-mixing technology, involved a more expansive testing program than that required by GE to meet their obligations to MDCERM. This expanded effort included three different leaching procedures, physical and microstructural tests, and analyses of leachates for volatile organic compounds (VOCs) and metals if these contaminants were detected in the untreated soil.

IWT, the stabilization/solidification technology developer, and Geo-Con, Inc., provider of the specialized drilling and mixing equipment, were participants in both the SITE and GE programs. Under the latter program, IWT and Geo-Con served as contractors to GE for the mandated test before the site remediation. In addition, under a cooperative agreement with EPA, IWT was designated as the SITE technology developer for the demonstration, and Geo-Con verbally agreed that its in situ procedures were to be evaluated.

The IWT process involved the in situ mixing of the service shop soil (which was contaminated with polychlorinated biphenyls), with a cement-organo clay mix referred to as HWT-20. Two 10x20-ft test sectors (designated B and C) were treated to a depth of 18 ft in Sector B and 14 ft in Sector C. These depths were defined by GE to treat all the soil containing at least 1.0 mg/kg of PCBs. Each sector was treated by creating thirty-six 3-ft-diameter columns of treated soil. The two sectors were designated by GE because they were expected to be high in PCBs. The developer claimed the wastes would be immobilized and bound into a hardened, leach-resistant, concrete-like solidified mass.

The major objectives of this SITE project were to determine the following:

1. Ability of the stabilization/solidification technology to immobilize PCBs. (If VOCs and heavy metals were detected in the untreated soil, their immobilization would need to be measured.)
2. Effectiveness, performance, and reliability of Geo-Con deep-soil-mixing equipment used for the in situ solidification (including continuity of operation, uniformity of mixing, and accuracy of column overlap).
3. Degree of soil consolidation (solidification) caused by the chemical additives.
4. Probable long-term stability and integrity of the solidified soil.
5. Costs for commercial-scale applications.

The following technical criteria were used to evaluate the effectiveness of in situ stabilization/solidification:

1. Mobility of the contaminants—Areas of high PCBs and VOCs were sampled, with the analytical emphasis on leaching characteristics. Three leachability tests were performed: the Toxicity Characteristic Leaching Procedure (TCLP) and two leach tests that evaluate solidified conditions, MCC-1P and ANS 16.1. Only the effectiveness with PCBs was evaluated, as the additive HWT-20 was not designed to immobilize VOCs or other contaminants. Permeabilities also were measured before and after soil treatment. These values indicate the degree to which the solidified material permits or prohibits the passage of water through the soil mass, and thus the degree of water contact with the contaminants.
2. Durability of the solidified soil mass—Core sections from the solidified mass were analyzed to determine uniformity and long-term endurance potential. However, if a chemical bond forms between HWT-20 and the PCBs, as claimed by IWT, then maintaining durability of the solidified mass to prevent the mobility of the contaminant becomes less important. The analyses obtained information on the following:
   - Integrity of the remediated soil columns at their interfaces with each other.
   - Unconfined compressive strength results as an indication of long-term durability.
   - Microstructural characteristics as a source of information on treated soil porosity, crystalline structure, and degree of mixing. These indicate the potential for long-term durability of the hardened mass.
   - Wet/dry and freeze/thaw weathering tests as information on weight loss. Permeability and unconfined compressive strength of the weathered samples also were performed, providing additional indications of short-term durability.

Procedure

The demonstration, utilizing IWT's HWT-20 additive with Geo-Con's deep-soil-mixing equipment, was performed on two 10x20-ft test sectors.

The Geo-Con/DSM deep-soil-mixing system of mechanical mixing and injection consisted of one set of cutting blades and two sets of mixing blades attached to a vertical drive auger, which rotated at approximately 15 rpm. Two conduits in the auger allowed for the injection of the additive slurry and supplemental water. HWT-20 additive was injected on the downstroke, with further mixing occurring on auger withdrawal. The treated 36-in. diameter soil columns were positioned in an overlapping pattern to cover the entire area.

A batch mixing system processed the feed additives. HWT-20 was conveyed by air from a supply truck to a storage silo. To treat three or four soil columns, a measured amount of water was fed to a 1,000-gal mixing tank. The HWT-20 was fed to the tank at a weight ratio to water of 4:3. A screw-type positive-displacement pump moved the slurry to the auger at an average rate of 0.18 lb of HWT-20/lb of dry soil. Water was fed separately to the drill rig on a ratio basis to the additive slurry. Sufficient water was provided to produce a final soil product containing 1.6-1.7 lb of water/lb of HWT-20.

Sampling and Analysis Program

Soil sampling, provided by EPA, was performed two weeks before, and five weeks after, the remediation of the test sectors. Samples were taken at soil column centers, at column interfaces, and at five locations around one anticipated hot spot in each sector. Samples were taken at three or four depths, from the top layer of unconsolidated sand, the limestone layer, and the lower unconsolidated sand layer. In Sector B, where the HWT-20 was injected to a depth of 18 ft, a sample at a fourth depth was also collected.

Samples of untreated and treated soil were collected for the following physical property measurements:

- Moisture content
- Bulk density
- Permeability
- pH (untreated soil only)
- Unconfined compressive strength (treated soil samples)
- Oil and grease and total organic carbon (untreated soil only)
- Weathering—wet/dry and freeze/thaw—(treated soil only).

Chemical analyses were performed to identify and quantify soil contaminants in both the untreated and treated soil. In addition, three different leaching tests were performed:

- TCLP—a commonly accepted procedure for measuring leachability of both organics and inorganics.
- ANS 16.1—This test simulates leaching from the intact solidified core by modeling a condition of percolating water flow that is sufficiently rapid to prevent it from becoming saturated.
- MCC-1P—simulates leaching from the intact, solidified core into relatively stagnant groundwater.

These latter two tests were drawn from the nuclear industry and modified to suit hazardous waste analysis.

In order to obtain information on potential long-term integrity, microstructural studies were performed on the untreated and treated soils. These analyses included:

- X-ray diffractometry—to identify crystalline structures.
- Microscopy—use of scanning electron microscopy and optical microscopy to characterize porosity, hydration products, and fractures.

Results and Discussion

The following results were obtained and are summarized in Tables 1 and 2:

- The chemical analyses of the untreated soils showed the highest PCB concentrations (Aroclor 1260) in Sector B, up to 950 mg/kg, with the maximum concentration in Sector C being 150 mg/kg. The maximum concentration of PCBs in the treated soil was 170 mg/kg, with all other values 110 mg/kg or less. The untreated soil at sample locations B-6, B-7, and B-8 also contained large quantities of VOCs (xylenes, chlorobenzene, and ethylbenzene)—from 160 to 1,485 mg/kg total—and some heavy metals (lead, copper, chromium, and zinc)—up to 5,000 mg/kg total metals. In the treated soil, the total VOCs ranged from 2 to 41 mg/kg, and the total metals, 80 to 279 mg/kg. These reductions may have been produced by the mixing action of the auger, which blended soils with both low and high concentrations of contaminants.
- The untreated-soil TCLP leachates showed PCB concentrations (Aroclor 1260) up to 13 µg/L. Leachates of all untreated soil samples below 63 mg/kg of PCBs were below the PCB detection limit of 1.0 µg/L, and all soil samples with PCB concentrations above 300 mg/kg showed detectable PCB concentrations in the leachate. For the soil samples with PCB concentrations between 63 and 300 mg/kg, some leachate samples had detectable quantities, but others did not. All leachates of treated soil samples were below 1.0 µg/L PCBs, the detection limit used for all samples. Seven treated soil leachates were analyzed a second time with the detection limit reduced to 0.1 µg/L, and four of the samples were below this detection limit. Thus, the IWT process appears to immobilize PCBs, but because of the very low values being measured, it cannot be confirmed by this project.
- The VOC concentrations in the untreated soil TCLP leachates ranged from 2,490 to 7,890 µg/L. The VOC concentrations in the treated soil leachates ranged from 325 to 605 µg/L. This reduction in VOC concentrations was likely due to a combination of factors. The largest one was probably the Geo-Con mixing operations, which blended high and low concentration soils.
- The total heavy-metal concentrations in the TCLP leachates ranged for the untreated soil from 320 to 2,650 µg/L and for the treated soil from 120 to 210 µg/L. As with the VOCs, this leachate reduction may have been a result of the reduction in metals concentrations in the soil caused by the Geo-Con mixing operation.
- In the special leach tests, ANS 16.1 and MCC-1P, performed on treated soil samples, PCBs and VOCs were not detected in any of the leachates.
- The oil and grease and total organic carbon contents of the untreated soil were both approximately 0.1% by wt., except at sample locations B-6, B-7, and B-8, where values up to 1.5% by wt. were measured. These values were too low to interfere with the cement hydration reactions
- The average permeability of the untreated soils was 1.8×10^{-2} cm/s, and ranged from 0.1×10^{-2} to 12×10^{-2} cm/s. Results obtained for the treated soil were 10^{-6} to 10^{-7} cm/s. These values essentially meet the EPA guideline of 10^{-7} cm/s for the maximum allowable value for hazardous-waste landfill liners. Because of the large decrease in permeability after soil treatment, groundwater will flow around, not through, the treated soil.
- The unconfined compressive strength (UCS) measured in both sectors was quite satisfactory, easily meeting the EPA guideline minimum of 50 psi. In Sector B values ranged from 75 to 579 psi. In Sector C, the range was from 247 to 866 psi. Sector C samples had

Table 1. Chemical Properties

Sample Designation*	PCB Concentrations: Untreated Soil, mg/kg	Untreated Soil TCLP Leachate, µg/L	Treated Soil, mg/kg	Treated Soil TCLP Leachate, µg/L
B-6	650	12.0 (15.0)	49	< 1.0 (0.15)
B-7	460	400.0 (250)	82	< 1.0 (0.12)
B-8	220	< 1.0	9.6	< 1.0
B-11	950	7.2 (0.33)	170	< 1.0 (< 0.10)
B-12	140	1.1	16	< 1.0
B-13	250	< 1.0	--	--
B-16	300	3.7 (0.50)	100	< 1.0 (< 0.1)
B-17	495	3.0 (1.0)	100	< 1.0 (0.20)
B-21	--	--	60	< 1.0
B-22	--	--	114	< 1.0
C-1	98	< 1.0	20	< 1.0
C-3	94	< 1.0	57	< 1.0
C-7	150	< 1.0	22	< 1.0
C-10	86	< 1.0	80	< 1.0 (< 0.10)

* Selected locations of highest PCB concentrations.
() Repeat leachate analysis of existing TCLP leachate analyzed to a detection limit of 0.1 µg/L.

Table 2. Average Physical Properties

	Sector B		Sector C	
	Untreated	Treated	Untreated	Treated
Moisture content, %	11.8	19.0	13.2	17.3
Bulk density, g/mL	1.51	1.85	1.56	1.94
Permeability, cm/s	1.46×10^{-2}	5.5×10^{-7}	3.5×10^{-2}	2.7×10^{-7}
Unconfined compressive strength, psi	--	290	--	536
Weathering tests				
wet/dry, wt % lost	--	0.39*	--	0.34*
freeze/thaw, wt % lost	--	7.2*	--	6.0*
pH	8.1	--	8.5	--
Oil and grease, %	0.3	--	0.1	--
TOC, mg/kg	4,380	--	2,300	--

* These values represent the weight loss of the test specimens. The wet/dry weight losses of the controls were approximately 0.1% less. For the freeze/thaw controls the absolute weight losses were in the range of 0.3% to 0.4%.

an average UCS of 536 psi higher than Sector B, with an average of 288 psi. A factor that may have contributed to this difference was the higher additive injection rate in Sector C compared to Sector B.

- The wet/dry weathering test results were satisfactory. They showed very low weight losses, 0.25% to 0.50% for the 12-cycle tests. The relative weight losses of test specimens to controls were very small, averaging about 0.1%. The UCS values of the wet/dry test and control specimens after 12 cycles of weathering were equal and the same as for the unweathered samples.
- The freeze/thaw tests showed large losses, up to 30.7% by wt. The weight loss of the controls was 0.25% to 0.70%. For the freeze/thaw specimens where weight losses exceeded 3%, the UCS values decreased dramatically, approaching zero for some samples. Permeabilities performed on eight weathered samples with low-to-moderate weight losses were equivalent to unweathered samples.
- The microstructural analysis, performed on each sample collected, showed that the IWT process produced a dense, homogeneous mass with low porosity. It also showed that variation of properties in the vertical and horizontal direction of the treated soil was absent, which indicated that mixing was quite satisfactory.
- The bulk density of the soil increased 21% after treatment, which equated to a volume increase of 8.5%. This is equivalent to a ground rise of approximately 18.4 in. in Sector B and 14.3 in. in Sector C, which agrees with the general observations made by the test observers. Although this volume increase is modest, it may still cause land contour problems in some small restricted areas.
- Total additive, water, and sodium silicate addition increased the treated soil weight compared to the untreated soil by an average of 32%. The average additive addition was 0.171 lb/lb of dry soil in Sector B, and 0.193 lb/lb of dry soil in Sector C, compared to values targeted by the developer of 0.131 lb in Sector B and 0.150 lb in Sector C, respectively. In Sector B, the dosage of additive for secondary columns (drilled after the primary columns were completed) was reduced by almost 30% compared to the primary columns.
- The demonstration operations lasted six days—three days on each sector. Operations were well organized and ran smoothly, although some minor difficulties were encountered, including the following:
  - —The locations of the soil columns deviated from the planned points, and therefore some untreated areas exist between columns. Nevertheless, because Geo-Con has since indicated that their auger actually creates a column slightly greater in diameter than 36 in., the untreated areas would be proportionally smaller.
  - —Automatic feed control could not be maintained, resulting in lean and rich injection areas. Manual control was

the predominant technique used. This difficulty was caused in part by trying to adapt a system designed for the larger 4-auger commercial unit to the 1-auger unit used in the demonstration.

- A major water leak occurred at the drill head, precluding the use of supplemental water for the last 21 columns. To save time, Geo-Con was instructed by GE to continue without repairing the leak.

With the experience gained by Geo-Con, these minor difficulties should be readily eliminated for a commercial operation.

Conclusions

A demonstration on the IWT in situ stabilization/solidification process, utilizing the Geo-Con deep-soil-mixing equipment, was performed on a narrow range of hazardous wastes, with low-to-moderate concentrations of PCBs and one localized area containing VOCs and heavy metals. Two test sectors,10 x 20 ft, were remediated to a depth of 18 ft in one sector and 14 ft in the other. Samples of untreated and treated soil were taken from the same locations in each test sector, and laboratory analyses were performed to obtain a comparison of physical properties and contaminant mobilities before and after soil treatment. Highlights of the results were as follows:

- Based on TCLP analyses, the PCBs appear to be immobilized. However, due to the very low PCB concentrations measured in the soil and leachates, it cannot be confirmed by this project.
- The physical test results were satisfactory (except for the freeze/thaw tests) indicating a potential for long-term durability of the hardened mass These results were as follows:
  - High unconfined compressive strength (average about 410 psi).
  - Soil permeability was improved by treatment four orders of magnitude, to an average of $4x10^{-7}$ cm/s.
  - Wet/dry weathered samples showed satisfactorily low weight losses.
  - Volume increased with treatment by 8.5%.
  - Freeze/thaw weathered samples showed unsatisfactorily large weight losses.
  - Microstructural studies showed the treated soil to have a dense, homogeneous structure of low porosity, which might give long-term durability.
  - Operations were well organized and ran smoothly; the difficulties experienced should be readily correctable.

*The EPA Project Manager, **Mary Stinson**, is with the Risk Reduction Engineering Laboratory, Edison, NJ 08837 (see below).*

The complete report, entitled "Technology Evaluation Report: SITE Program Demonstration Test, International Waste Technologies In Situ Stabilization/Solidification, Hialeah, Florida," consists of two volumes:

"Volume I" (Order No. PB 89-194 161/AS; Cost: $21.95, subject to change) discusses the results of the SITE demonstration.

"Volume II" (Order No. PB 89-194 179/AS; Cost: $85.95, subject to change) contains the technical operating data logs, the sampling and analytical data, and the quality assurance data.

Both volumes of this report will be available only from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650

A related report, entitled "SITE Program Applications Analysis Report: Assessment of Superfund Applications for International Waste Technologies In Situ Stabilization/Solidification," which discusses application and costs, is under development.

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